Energy Efficient Topology Control Approach for Mobile Ad hoc Networks

T.S.Asha[1] and Dr.N.J.R.Muniraj[3]

**[1] Research Scholar, Karpagam University
Coimbatore**

**[2] Principal, Tejaa Shakthi Institute of Technology
Coimbatore**

Abstract

In MANET, energy consumption and network connectivity are the two very important issues. Due to the mobility of the nodes, the network partition occurs unlimitedly. To avoid this, several researches concentrated on this issue. But it is not focused on constantly. In this work, we developed Energy Efficient Topology Control Approach (EETCA) is developed to attain both network connectivity and energy consumption. It consists of three main parts. Network and Interference model is introduced to make sure the network connectivity. Energy based topology control is developed to ensure more energy efficiency. Here the power consumption is also determined and validated in each and every route. Energy level of node is equally maintained in both route discovery and route maintenance phase. Packet format of EETCA is proposed which consists of power consumption and link availability. If any link is broken more power consumption will be occupied. So the status of link availability is keep on monitoring during this phase. By using the extensive simulation results using Network Simulator (NS2), the proposed scheme EETCA achieves better network lifetime, packet delivery ratio, less overhead and end to end delay than the existing schemes like NCTC and DM.

Keywords: *MANET, Interference, network connectivity, network lifetime, packet delivery ratio, end to end delay, overhead.*

1. Introduction

A. Mobile Ad Hoc Networks (MANET)

Mobile ad-hoc network is an independent system of mobile nodes connected by wireless links forming a short, live, on-the-fly network even when access to the Internet is unavailable. Nodes in MANETs generally operate on low power battery devices. These nodes can function both as hosts and as routers. As a host, nodes function as a source and destination in the network and as a router, nodes act as intermediate bridges between the source and the destination giving store-and-forward services to all the neighbouring nodes in the network. Easy deployment, speed of development, and decreased dependency on the infrastructure are the main reasons to use ad-hoc network.

B. The topology control problem in MANET

In mobile ad hoc wireless communication, each node of the network has a potential of varying the topology through the adjustment of its power transmission in relation to other nodes in the neighborhood. In contrast, wired networks have fixed established pre-configured infrastructure with centralized network management system structure in place. Therefore, the fundamental reason for the topology control scheme in MANET is to provide a control mechanism that maintains the network connectivity and performance optimization by prolonging network lifetime and maximizing network throughput. A MANET topology can depend on uncontrollable factors such as node mobility, weather, interference, noise as well as controllable factors such as transmission power, directional antennas and multi-channel communications.

A bad topology can impact negatively on the network capacity by limiting spatial reuse capability of the communication channel and also can greatly undermine the robustness of the network. Network capacity means that the bandwidth and ability for it to be used for communication. A network partitioning can occur in a situation where the network topology becomes too sparse. Similarly, a network which is too dense is prone to interference at the medium access (MAC) layer, the physical layer of the network. So the network should neither be too dense nor too sparse for efficient communication amongst nodes to take place.

C. Problem Definition

The problem identified in contemporary research literature pertaining to topology control in MANET is that most of the topology control algorithms do not achieve reliable and guaranteed network connectivity.

2. Related work

Dalu et.al [1] proposed topology control algorithm to maintain the topology without any control message. If any node goes out of range, communication would not get affected. The communication range is higher than the maximum allowable distance. The algorithm controls the movement of node with respect to a target node to make more connectivity of the network through the topology maintenance. Here there is no need to change routing table as the connectivity o the network is maintained throughout the communication phase.

Manvi and Hurakadli [2] proposed agent based model to address the aspect of topology discovery and routing. In this model, three agents are used. Manager Agent handles the activities of route discovery and routing agency. Monitoring Agent is deployed to monitor resources like transmit power, battery life, bandwidth and reliability. Discovery and Routing Agents discover the links between the mobile nodes, perform routing information fusion and build pre-computed paths.

S.Muthuramalingam and R.Rajaram, [3] proposed clustering algorithm which reduces the number of clusters and optimize the load balancing factor. Network lifetime is also improved. This algorithm does topology management by the usage of coverage area of each node and power management based on mean transmission power within the context of wireless ad-hoc networks. By reducing the transmission range of the nodes, energy consumed by each node is decreased and topology is formed.

Ngo duc Thuan et.al [4] proposed Local Tree based Reliable Topology to update the effects on network connectivity. It preserves edge connectivity which is more reliable. This scheme considered to be the scalable and applicable scheme that is used in MANET. By experimental results, the proposed topology achieves high transmission range and more network connectivity than that of existing scheme.

Fujian Qin [5] proposed algorithm to construct topology that can meet the QoS requirements and decrease the total transmission power in the network. At physical layer, it is adopted that cooperative communication which combines partial signals to obtain completer information. At network layer, the whole topology information can be collected when it is not required to perform packet forwarding. Energy Efficient Topology Control and QoS formulation are proposed to achieve more network connectivity.

Bharathi and Saranya [6] proposed secure adaptive distributed control algorithm which aims at topology control and performs secure self organization. It consists of four phases like Anti node detection, Cluster formation, Key distribution and key renewal. In anti node detection, both encryption and decryption is performed to find the anti node. In cluster formation, cluster head is selected to ensure more information about network. Both key distribution and key renewal phase are developed to provide more integrity of data.

Jie Wu and Fei Dai [7] proposed mobility sensitive topology control method that consists of local view consistency based on synchronous and asynchronous method. A local view consists of locations of 1-hop neighbors within a normal transmission range. It is collected via exchanging "Hello" messages among neighbors and used to select logical neighbors at each node. The weak consistency is introduced to reduce the maintenance cost without any synchronization among neighbours.

Karunakaran and Thangaraj [8] proposed topology control algorithm based on power level. In this technique, topology control is maintained within each cluster. Initially, the cluster-head is selected based on factors power level, stability and connectivity. After the cluster-head selection, the connectivity of each node of the cluster with the cluster-head is checked. If the connectivity is low then the connectivity is increased by increasing the power level. In a cluster, cluster-head which is incharge of a dense area will experience low inter node interference. If there are any unidirectional links in the network then the cluster-head will form bidirectional link with it. If there are no unidirectional links, then the cluster-head will start linking up with the nodes that are not its direct neighbors. If the connectivity is higher than a threshold, then the cluster-head reduces the power level.

Suchismita Rout et.al [9] proposed Distance based Sleep Scheduling to deal with topology control problem at network layer and also help to reduce total energy consumption of network to maximize network lifetime. In this protocol, it takes farthest node in its transmission range for routing. That node is geographically closer to the destination. The number of nodes in packet transferring is less. Energy conservation is done by utilizing energy of small set of nodes. Sleep based approaches for the other idle mode node minimizes energy consumption of the network.

Uma and Shantharajah [10] proposed an energy efficiency analysis topology control algorithm. Our algorithm dynamically adjusts transmission power of mobile nodes to construct new topology which can meet bandwidth and end-to-end delay constraints as well as minimize the total energy consumption in network. This model has been compared with AODV and DSDV protocols in CBR traffic model and the simulation results show that the proposed algorithm has a better performance.

Aron et.al [11] proposed the notion of energy management in the context of heterogeneous wireless mesh networks was introduced. The objective was to develop a minimum-energy distributed topology control that ensures a reduction in the amount of energy consumed per node during transmissions and without loss of connectivity. A three phased topology control algorithm is proposed that executes distributively per node. A node uses only the locally available information to determine the nodes that should be its logical neighbours at any given time. The execution of the algorithm is asynchronous from node to the next till convergence in the transmission power per node is achieved thus runs in one pass thereby reducing concerns on control overheads.

Xiang-Yang Li et.al [12] proposed power assignment and routing protocols and performed extensive simulations to study the performance of our unicast routing protocols. When there is only one common source node, we show that our power assignment and routing are optimal. It is also presented a multicast routing protocol whose energy consumption is no more than two times of the minimum in a one-to-one communication model.

Joao B.D. Cabrea et.al [13] explored theoretic investigation of topology control in MANET. The Local information no topology algorithm is proposed to ensure more node degree. In this work stability is maintained well but the node connectivity is not well improved. Maximum power is achieved at each level.

Quansheng Guan [14] explored Capacity-Optimized Cooperative (COCO) topology control scheme to improve the network capacity in MANETs by jointly considering both upper layer network capacity and physical layer cooperative communications. They have introduced physical layer cooperative communications, topology control, and network capacity in MANETs. The network capacity of MANETs is improved with cooperative communications.

Atsushi yoshinari et.al [15] proposed mechanism with an adopted topology control technique, based on a localized algorithm, can maintain local connectivity which results in keeping global network connectivity although the network is dynamic. In the proposed topology update mechanism, the update interval in each node is determined based on the transmission range and mobility information of its adjacent nodes so that the network connectivity is guaranteed.

Srinivas Rao et.al [16] proposed power management schemes looks into two directions. First is to balance power consumption during data transfer and secondly to reduce the power consumed in case of a route failure. By balancing power consumption we can avoid the death of some critical nodes caused by excessive power consumption. Reducing power consumption intends to prolong the lifetime of each node which in turn extends the lifetime of the entire network. Each approach proposed in the following sections improves the network's performance either by balancing the power across the network or by reducing the power consumed by the nodes across the network.

The paper is organized as follows. The Section 1 describes introduction about MANET, topology control problem in MANET. Section 2 deals with the previous work which is related to the topology control. Section 3 is devoted for the implementation of Energy Efficient Topology Control. Section 4 describes the performance analysis and the last section concludes the work.

3. Implementation of Energy Efficient Topology Control Approach

In the proposed Energy Efficient Topology Control Approach, there are three phases involved. In first phase, we aim to propose network model. In second phase, we propose the energy based topology control approach which ensures the more energy efficiency of the node. In third phase, new packet format is proposed which contains the status of energy and interference level.

3.1 Network and Interference model

Let G be the collection of mobile nodes K denotes the graph on G in which there is an edge from node m to n. Let τ be the topology status which depends on energy consumption, throughput, load balancing, network connectivity and mobility.

In a centralized model of mobile networks, the connected topology is constructed that minimizes the maximum interference. It is also introduced that centralized and localized methods for reducing link interference with spanning ratio. In this algorithm, edges are sorted by their weights in ascending order. Starting from the edge with minimum weight, in each iteration of the algorithm an edge *mn* is processed. If nodes *m* and *n* are already connected in the induced graph, the edge *mn* is just ignored and otherwise it will be added to the topology. The algorithm continues till a connected graph is constructed. The time complexity of this approach is $O(m \log m + hn)$ where h is the number of links in the final structure H. The illustration of Energy Efficient topology Model is shown in fig.1.

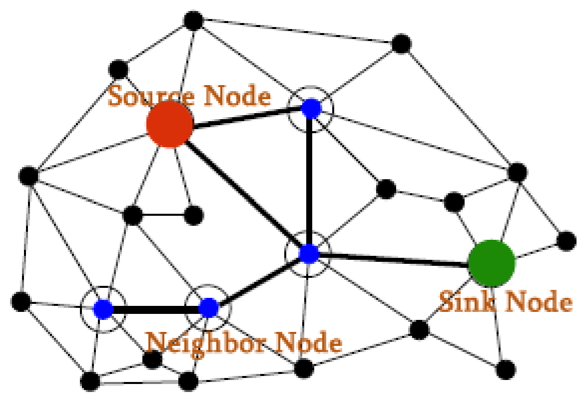

Fig.1. Topology Model of EETCA

A. Energy Efficient Topology Control

In this scheme, link based topology information is used to maintain a connected topology. If a route update indicates that a link failure has occurred such that the network is no longer connected, the appropriate nodes increase their transmit power until it is connected. This technique depends heavily on routing protocol performance, because changes in network connectivity can trigger further routing updates.

The main issue of minimum energy consumption model is to minimize the total energy consumed in forwarding a packet from source to destination mobile nodes. It can exploit path loss and packet loss by forwarding traffic using a sequence of low power transmissions rather than a single direct transmission.

The signal to noise plus interference ratio (SNIR) for successful transmission at the receive node must be greater than some threshold, which depends on the bit error rate. In a basic path loss model, received signal strength decreases exponentially with distance. The measurement data presented earlier show that it is necessary to account for energy consumed in both transmitting and receiving when evaluating the energy cost of a path. The former depends on the transmit power used at each hop, while the latter is roughly constant. If a relay node is added to a minimum hop-count path, the energy saved though reduced transmit power must compensate for the energy consumed by the overhead of the extra transmit and receive operations.

The cost of transmitting a packet over minimum energy consumption link is given as,

$$C(N,t)=\max_{k} N_k(t) \tag{1}$$

$$N_k(t)=\min_{q} E_q(t)/P_{kq}(t) \tag{2}$$

Where t is time $E_q(t)$ is the remaining energy of the node q assumed to be known from hardware. $P_{kq}(t)$ is the transmit power of node k in route q as stored in the received packet.

Route discovery and route maintenance are the main components of Energy based Topology model. Initially the route discovery is initiated when the route cache at the source node does not have any entry for the destination node. The source node broadcasts a route request message.

A node that receives the request can do one of two things;

- Forward the request after appending its own id if it's not the destination, or reply using its cached routes.
- The destination would reply and reply messages propagate back to the source. A node ignores a request if it has already processed it.
- It uses the route with maximum remaining lifetime. Remaining lifetime of a node in a route is defined as remaining node energy divided by power required to transmit packet to the next node in the route.
- Remaining lifetime of a route is then minimum of remaining life of nodes in the route. Following the notation used.

Route maintenance is achieved by using Medium Access Control layer acknowledgments to confirm retrieval of packet information about a broken link is propagated back along the route. Nodes invalidate all routes containing the broken link. The source then tries to find the next route in cache. If it is node, the route discovery is initiated.

More precisely, nodes upon receiving of the packets can calculate minimal energy necessary to reach their single hop neighbors (these associations are stored in power table) using the following formula:

$$P_{\min}=P_{tx}-P_{recv}+P_{threshold}+P_{margin}-P_{drop}$$

Where P_{min} is the minimum required power of the sender to destination node. P_{tx} and P_{recv} are the transmitter and received power. $P_{threshold}$ is threshold power. P_{margin} is the margin to safeguard agains such as channel fluctuation and mobility. The following steps are proposed to verify link availability and power consumption level.

Input : An instance K of MANET. Let f be the value of the maximum speed times the unit time interval, and let $P_{maximum}$ be the common transmission power.

Output: The power assignments to nodes $\{p_1, p_2 \ldots\ldots p_n\}$

Where K is the movements connected.

Steps: Each node C_m independently. The following steps are used to estimate that packet transmissions utilizes *Pmax* before P_i is computed.

1. $R_k' = R_k - 2d$, where R_k is the maximum transmission range of C_m.
2. Each time the transmission range of C_m is updated to R_k'.
3. Sort C_m 1- hop neighbors in to the list $L_k = (C_1, C_2, \ldots\ldots C_m)$ in ascending order by the received signal strength $\{C_{mk}\}$.
4. Broadcast List L_k to every node in L_k'.
5. For $C_{mk} \in L_k$ in ascending order do

If $\{\exists_k > l : C_{mk'} \in L_k, C_{nk} = C_{nk}', |C_{nk}| < |C_{nk}'|\}$, then eliminate c_{nk} from L_k ; else break out of For the Loop.

6. Let d_m be the distance between C_k and the first node in L_k.
7. $p_k \leftarrow PL(d_m + 2r)$ where Power consumption threshold level maps distance to power according to the communication radio model.

3.2 Packet format of EETCA

Source/ Destination	Next hop	Link Availability	Hop count	Power consumption	CRC
4	1	4	2	4	1

Fig.2.Proposed Packet format

In fig 2, first field occupies source and destination address. It occupies 4 bytes. In second field next hop is determined to achieve shortest path. In third, link availability occupies 4 bytes which is monitored to ensure network connectivity. Power consumption of all the nodes are determined and send back to source node. It occupies 4 bytes. Cyclic Redundancy Check is in the last field for error detection and error correction. It occupies 1 byte. It can be used by upper level routing algorithm to find a least weighted path. The network topology under EETCA is all the nodes in L and their individually perceived logical neighbor relations. The flow chart of EETCA is shown in fig.3.

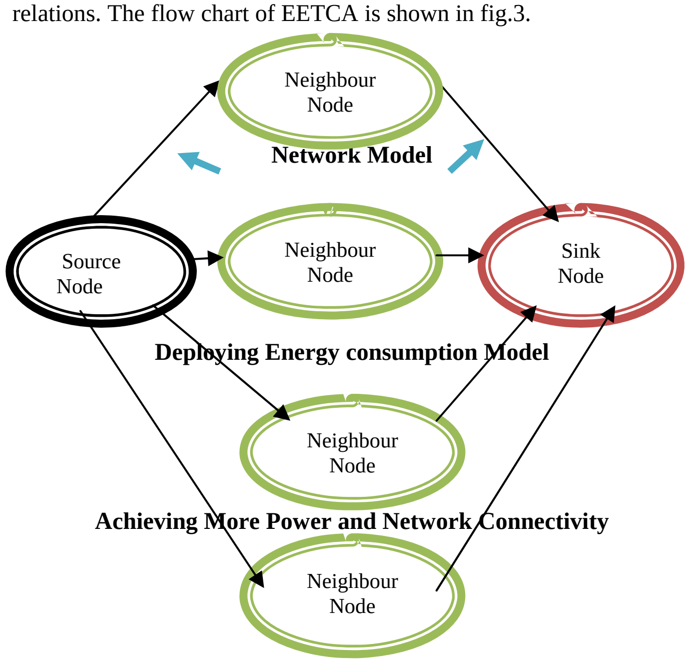

Fig.3.Flowchart of EETCA

4. Performance Analysis

Network Simulator (NS) is an event driven network simulator developed at UC Berkeley that simulates variety of IP networks.

It implements network protocols such as TCP and UPD, traffic source behavior such as FTP, Telnet, Web, CBR and VBR, router queue management mechanism such as Drop Tail, RED and CBQ, routing algorithms such as Dijkstra, and more. NS also implements multicasting and some of the MAC layer protocols for LAN simulations.Currently, NS (version 2) written in C++ and OTcl (Tcl script language with Object-oriented extensions developed at MIT) is available.

We use NS2 to simulate our proposed algorithm. In our simulation, 200 mobile nodes move in a 1200 meter x 1200 meter square region for 80 seconds simulation time. All nodes have the same transmission range of 300 meters. The simulated traffic is Constant Bit Rate (CBR). Our simulation settings and parameters are summarized in table 1.

Table 1. Simulation settings and parameters of EETCA

No. of Nodes	200
Area Size	1200 X 1200
Mac	802.11
Radio Range	300m
Simulation Time	50 sec
Traffic Source	CBR
Packet Size	512 bytes
Mobility Model	Random Way Point
Protocol	DSR
Packet rate	6pkts/sec

Performance Metrics

We evaluate mainly the performance according to the following metrics.

Control overhead: The control overhead is defined as the total number of routing control packets normalized by the total number of received data packets.

Packet Delivery Ratio: The packet delivery ratio (PDR) of a network is defined as the ratio of total number of data packets actually received and total number of data packets transmitted by senders.

Node degree: It is the important metric to evaluate the performance of topology control algorithms. If the node degree is higher, it indicates that higher collision will be. So value of node degree should be kept small.

Network connectivity ratio: It determines the nodes are connected in the intermediate region. It should be kept small while varying the average speed.

End-to-End Delay: The End-to-End delay is defined as the difference between two time instances: one when packet is generated at the sender and the other, when packet is received by the receiving application.

The simulation results are presented in the next part. We compare our proposed scheme EETCA with NCTC and DM [17] in presence of topology control environment. Figure 4 shows the results of connectivity ratio for varying the mobility from 5 to 25. From the results, we can see that EETCA scheme has slightly lower connectivity ratio than the NCTC and DM method because of light weight calculations.

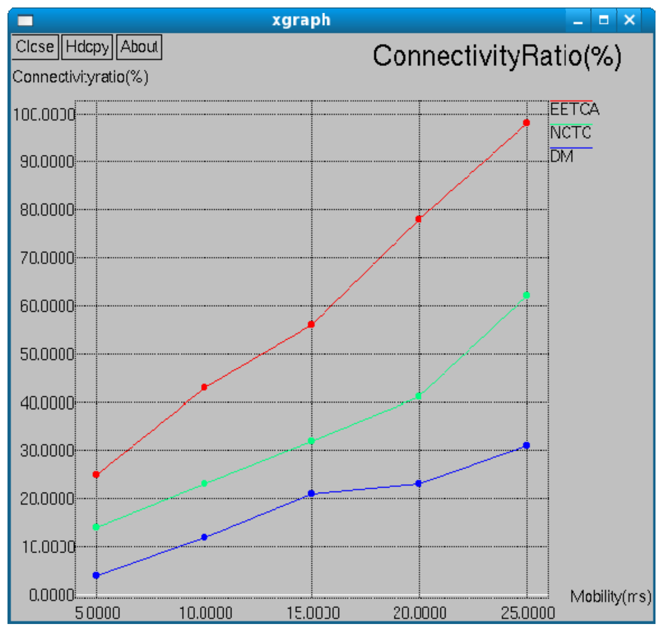

Fig.4. Mobility Vs Connectivity Ratio

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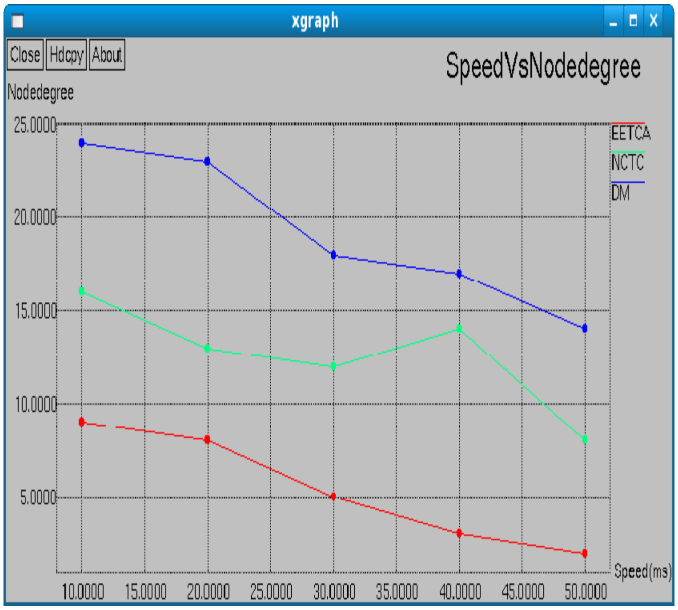

Fig. 5. Speed Vs Node degree

Fig. 5, presents the comparison of node degree It is clearly shown that the node degree of EETCA has low overhead than the NCTC and DM

Figure 6 shows the results of Time Vs End to end delay. From the results, we can see that EETCA scheme has slightly lower delay than the NCTC and DM scheme because of stable routines.

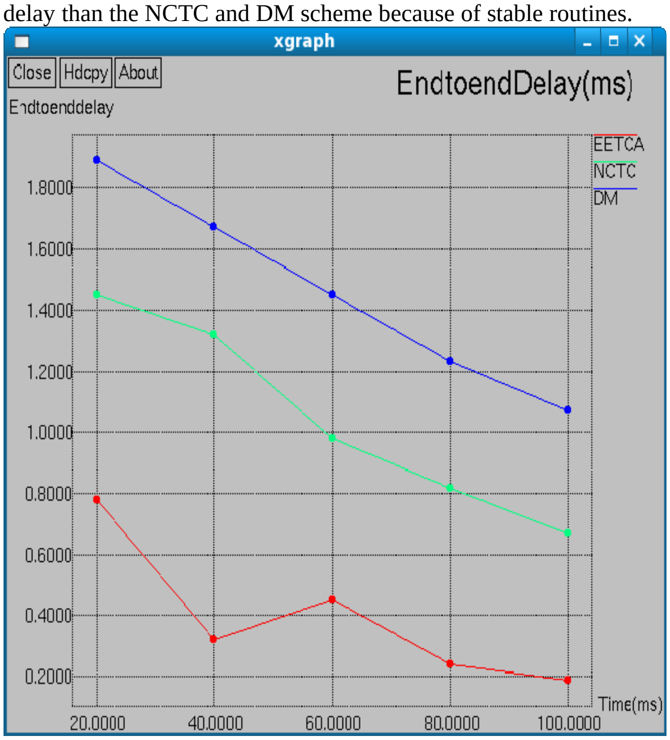

Fig. 6. Time Vs End to end delay

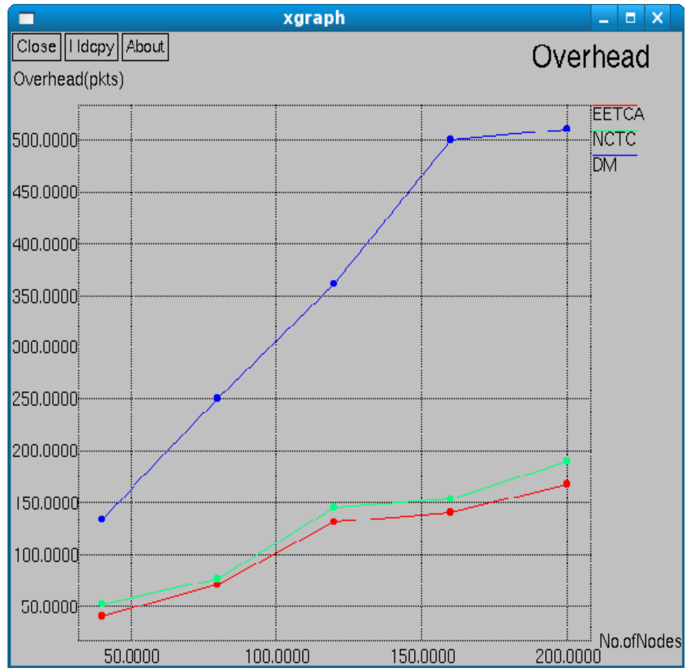

Fig.7.No. of Nodes Vs Overhead

Fig. 7, presents the comparison of overhead while varying the nodes from 0 to 200. It is clearly shown that the of EETCA has low overhead than the NCTC and DM method.

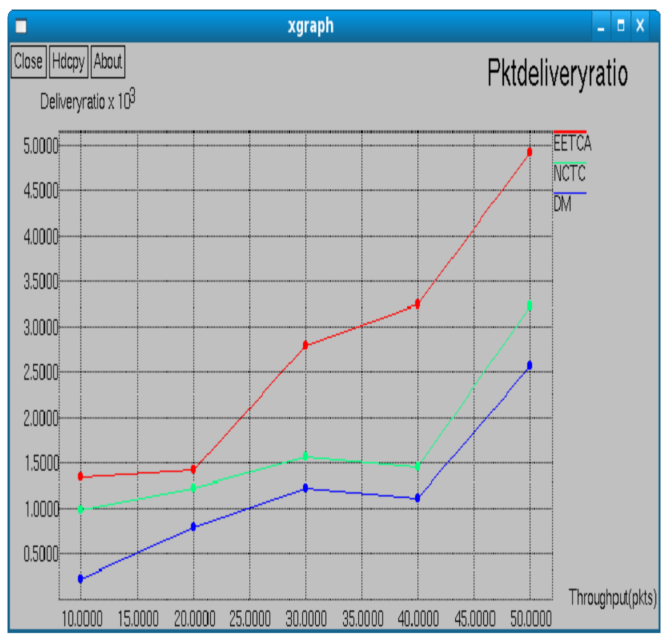

Fig.8. Throughput Vs Packet Delivery Ratio

Figure 8 show the results of average packet delivery ratio for the throughput 10, 20…50 for the 200 nodes scenario. Clearly our EETCA scheme achieves more delivery ratio than the NCTC and DM scheme since it has topology control features.

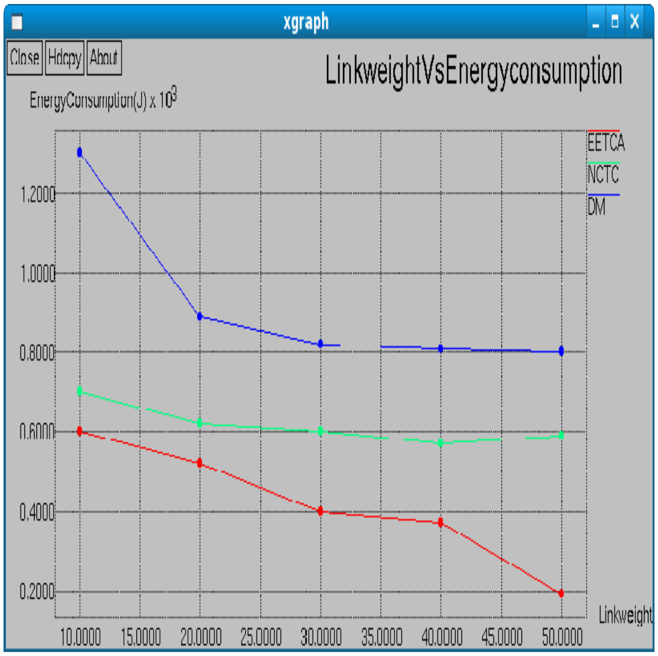

Fig.9. LinkWeight Vs Energy Consumption

Figure 9 show the results of energy consumption for the link weight 10, 20…50 packets for the 200 nodes scenario. Clearly our EETCA scheme achieves consumes less energy than the NCTC and DM scheme since it has topology control features.

5. Conclusions

Mobile nodes are communicating without any access point in MANETs. Due to the uncontrolled topologies, the more interference and more energy consumption is introduced in the networks which degrades the performance of network connectivity. In this paper, we have introduced the Energy Efficient Topology Control Approach to make the correct balance between the energy efficiency and network connectivity. In first phase, we have achieved low interference using based on the recommendation of neighbor nodes. In second phase, the energy based efficient topology control is introduced to extend the network lifetime and energy efficiency of MANET. Packet format is designed and integrated among the network to keep on monitoring the power consumption and link availability. By simulation results we have shown that EETCA achieves good packet delivery ratio, better network lifetime while attaining low delay, overhead, while varying the number of nodes, node velocity and mobility than our previous scheme NCTC and existing scheme DM.

6. References

[1] S. S. Dalu, M. K. Naskar and C. K. Sarkar, " Implementation of a Topology Control Algorithm for Mobile Ad hoc Networks Using Pursue Mobility Model", Journal of Applied Computer Science, Vol.2, no.2, 2008, pp.14-20

[2] S.S.Manvi and J.J.Hurakadli, "An agent-based model for topology discovery and routing information fusion in mobile ad-hoc networks", Journal of Indian Institute of Science, Vol.86, pp.553-568.

[3] S.Muthuramalingam and R.Rajaram, "A Transmission Range based Clustering Algorithm for Topology Control MANET", International journal on applications of graph theory in wireless ad hoc networks and sensor networks (GRAPH-HOC) Vol.2, No.3, 2010, pp68-76.

[4] Ngo Duc Thuan, Hiroki Nishiyama, Nirwan Ansari and Nei Kato, " On Performance Evaluation of Reliable Topology Control Algorithms in Mobile Ad Hoc Networks", IEEE Conferences, 2010, pp.1-5.

[5] Fujian Qin, "QoS Topology Control with Energy Efficiency for MANET", Journal of Convergence Information Technology, Volume6, Number 6, 2011, pp.300-307.

[6] R. Bharathi , Saranya. A.V, " High Throughput Analysis Using Topological Control & Authentication Scheme in MANET", International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 3, 2013, pp.857-861.

[7] Jie Wu and Fei Dai, "Mobility-Sensitive Topology Control in Mobile Ad Hoc Networks", Proceedings of the 18th International Parallel and Distributed Processing Symposium, 2004, pp.1-29.

[8] S. Karunakaran and P. Thangaraj, "Topology Control Using Efficient Power Management", Journal of Computer Science, Vol.7, No.4, 2011, pp.561-567.

[9] Suchismita Rout, Ashok Kumar Turuk and Bibhudatta Sahoo, " Energy Aware Routing Protocol in MANET using Power Efficient Topology Control Method", International Journal of Computer Applications (0975 – 8887) Volume 43, No.5, 2012, pp.33-42.

[10] S. Uma and S.P.Shantharajah, " MANET Energy efficiency analysis using MST based topology control algorithm and comparison with reactive and proactive protocols", International Journal of Advances in Computer Networks and its Security , Volume 2, Issue 2, pp.23-27.

[11] F. O. Aron, T. O. Olwal, A. Kurien, and M. O. Odhiambo, "A Distributed Topology Control Algorithm to Conserve Energy in Heterogeneous Wireless Mesh Networks", World Academy of Science, Engineering and Technology, 2008, pp.530-536.

[12] Xiang-Yang Li, Yu Wang, Haiming Chen, Xiaowen Chu, Yanwei Wu and Yong Qi, "Reliable and Energy-Efficient Routing for Static Wireless Ad Hoc Networks with Unreliable Links", IEEE Transactions on Parallel and Distributed Systems, Vol. 20, No. 10, October 2009, pp.1408-1421.

[13] Joao B. D. Cabrera, Ram Ramanathan, Carlos Gutierrez, and Raman K. Mehra , "Stable Topology Control for Mobile Ad-Hoc Networks", IEEE Communications Letters, Vol. 11, No. 7, 2007, pp.574-576.

[14] Quansheng Guan, F.RichardYu, Shengming Jiang and Victor C.M.Lung, "Topology Control in Mob,ile Ad

hoc Networks With Cooperative Communications", IEEE Wireless communications, 2012, pp.2-7.

[15] Atsushi Yoshinari, Hiroki Nishiyama, Nei Kato, and Dan Keun Sung, "Dynamic Topology Update Mechanism in Local Tree-based Reliable Topology (LTRT) based MANETs," IEEE International Conference on Communications (ICC 2012), Ottawa, Canada, Jun. 2012, pp.1-6.

[16] Dr D Srinivas Rao, Jooby Ann Thomas and Sake Pothalaiah, "QoS through Power Control in MANETs using AODV Protocol", International Journal of Computer Applications (0975 – 8887) , Volume 31– No.9, October 2011, pp.23-29.

[17] Hiroki Nishiyama, Thuan Ngo, Nirwan Ansari, and Nei Kato, "On Minimizing the Impact of Mobility on Topology Control in Mobile Ad Hoc Networks," IEEE Transactions on Wireless Communications, vol.11, no.3, pp.1158-1166, Mar. 2012.

Mrs. T.S. Asha is presently working as the Associate professor in N S S College of Engineering, Palakkad. She has 20 years of teaching experiences and published one international journal and five national papers. She had taken her B.E Degree from The Indian Engineering College, Vadakkankulam in 1990. She has her M Tech degree in Opto Electronics and Laser technology from Cochin university of Science and Technology. Her research area include Wireless mobile communication and Optical communication.

Dr. N.J.R.Muniraj is presently working as a Principal of Tejaa Shakthi institute of Technology, Coimbatore. He has more than 23 years of teaching and five years of industrial experience. He has presented more than 40 National and International papers and published fifteen international journal papers. His research area includes VLSI Signal Processing, Neural Networks, Image Processing and MEMS. He is also heading the Tejaa Shakthi Innovation centre.